ME-87-04

Improvements in Grouts and Grouting Techniques for Cable Ducts

Ministry of Transportation and Communications
Ontario

Research and Development Branch

ME-87-04

Improvements in Grouts and Grouting Techniques for Cable Ducts

B.B. Hope
A.K.C. Ip

Queen's University, Kingston

Published by
The Research and Development Branch
Ontario Ministry of Transportation and Communications
Hon. Ed Fulton, Minister
D.G. Hobbs, Deputy Minister

Published without prejudice as to the application of the findings. Crown copyright reserved; however, this document may be reproduced for non-commercial purposes with attribution to the Ministry.

For additional copies, write:
The Editor, Technical Publications
Room 320, Central Building
1201 Wilson Avenue
Downsview, Ontario
Canada M3M 1J8

Telephone: (416) 235-7635
Infotex Electronic Mail: 23:MIN006

March 1987

Technical Report Documentation Page

Improvements in Grouts and Grouting Techniques for Cable Ducts

Author:	B.B. Hope, A.K.C. Ip
MTC No.:	ME-87-04
Date:	March 1987
Published by:	The Research and Development Branch Ontario Ministry of Transportation and Communications
MTC Contact:	Hannah Schell
Abstract:	Corrosion protection for prestressing tendons in post-tensioned structures is provided by grout introduced into the void between the tendons and surrounding duct, and the degree of protection afforded is strongly dependent upon the quality of the grout. Concerns associated with the present grout formulation used by the Ministry of Transportation and Communications (MTC) are its high chloride permeability and fast-thickening characteristics. The purpose of this investigation was to improve the current MTC grout formulation, and to examine the present field procedure used to grout prestressing cable ducts and if necessary to make recommendations for improvements. A test program was carried out to evaluate various types of tests grouts containing pozzolanic materials and commercial grouting admixtures. During the initial screening stage of the program, the flow time, expansion, bleeding characteristics, viscosity, compressive strength, absorption, density and pH were examined. During the final evaluation stage, electrical resistivity, chloride permeability and corrosion suseptibility of the most promising grout mixtures were evaluated. The most promising grout formulation was found to be a combination of type 10 cement, silica fume, aluminum powder and water reducer. Recommendations for improving field procedures include premixing the dry grout ingredients before use in the field, and introduction of flow time measurement as a means of control.
Comments:	Final Report of Research and Development Branch Project No. 22163 conducted under the Ontario Joint Transportation and Communications Research Program
Key words:	grouts, grouting procedure, post-tensioned structures, prestressing steel, corrosion protection
Distribution:	MTC Head Office and Regions, other highway agencies and corrosion researchers
Copyright Status:	Crown copyright

Table of Contents

List of Tables 2

List of Illustrations 3
1. INTRODUCTION 1
2. TEST MATERIALS 2
  2.1 Silica fume 2
  2.2 Flyash 2
  2.3 Latex 3
  2.4 Aluminum powder 3
  2.5 Calcium nitrite 3
3. TEST PROGRAM 4
  3.1 Initial screening stage 4
  3.2 Final evaluation stage 5
  3.2.1 Electrical resistivity 5
  3.2.2 Chloride permeability 5
  3.2.3 Corrosion susceptibility 5
  3.2.4 Strength and expansion 6
4. RESULTS AND DISCUSSION 6
  4.1 Initial screening stage 6
  4.1.1 MTC mixes 6
  4.1.2 Silica fume (SF) mixes 7
  4.1.3 Calcium nitrite (CN) mixes 8
  4.1.4 Latex (LA) mixes 8
  4.1.5 Flyash (FA) mixes 9
  4.1.6 Proprietary grouting admixtures (PROP) 10
  4.1.7 Summary 12
  4.2 Final evaluation stage 12
  4.2.1 Electrical resisitivity 12
  4.2.2 Chloride permeability 13
  4.2.3 Corrosion susceptibility 13
  4.2.4 Strength and expansion 14
  4.2.5 General observation 14
5. FIELD PROCEDURES 15
6. RECOMMENDATION 16
References 17
Appendices 32

List of Tables

Table 1. Mix ingredients for test grouts 19
Table 2. Test result summary from initial screening stage 20
Table 3. Rapid chloride permeabilities of test grouts 21
Table 4. Corrosion measurements of test grouts 22
Table 5. Strength and expansion of 10 % silica fume mix 23

List of Illustrations

Figure 1. A typical test slab 24
Figure 2. External cathode for corrosion measurement 25
Figure 3. Test arrangement for corrosion measurement 26
Figure 4. Viscosity of test grouts 27
Figure 5. Compressive strength for test grouts 28
Figure 6. Effect of silica fume on 28-day compressive strength 29
Figure 7. Effect of calcium nitrite on viscosity 30
Figure 8. Electrical resistivities for test grouts 31

1. INTRODUCTION

The protection against corrosion of the prestressing tendons in post tensioned structures is provided by the grout introduced into the void between the tendons and duct, and the degree of protection afforded is strongly dependent upon the quality of the grout.

Prestressing tendons are very susceptible to corrosion damage because of the high steel stress and small wire diameter. If the tendons are allowed to corrode there is a real danger of eventual structural collapse with little or no advance warning. It is imperative, therefore, that the corrosion protection afforded by the grout is the best protection possible.

The traditional grout formulation has been composed of cement, water, workability admixture usually with retardation properties, and aluminum powder as an expansion aid. The field procedure used to fill the voids utilizes a positive displacement pump 0.6 MPa to 1.0 MPa pressure and capable of filling the largest void in 20 minutes. One way flow of grout is required and high points in the void are ducted to allow the escape of air and water during grouting.

The present grout formulation used by the Ministry of Transportation and Communications (MTC) consists of Type 30 cement, non-chloride water reducer, and fine aluminum powder. The dosages of water reducer and aluminum powder are approximately 0.28 % and 0.005 % by mass of cement, respectively. The maximum water/cement ratio is 0.50 for cables less than 45 m long and is 0.55 for cables 45 m long or over.

Two major concerns associated with the MTC grout mixture (1): high chloride permeability and fast-thickening characteristics. The high chloride permeability of the grout would make the prestressing tendons susceptible to corrosion, and the rapid thickening may cause problems in pumping.

The purpose of this investigation was:

1. To improve the current MTC grout formulation.
2. To examine the present field procedure used to grout prestressing cable ducts and, if necessary, to make recommendations for improvement.

To achieve objective 1, a test program was carried out to evaluate various types of test grouts containing pozzolanic materials and commercial grouting admixtures, and the grout that showed the most promising properties was identified. The MTC grout was used as the control for comparison purpose.

For objective 2, a field trip was made to observe the present field procedure for grouting and recommendations for improved procedure were made.

Section 2 of this report briefly describes the background of some of the test materials. Sections 3 and 4 describe the test program and test results, section 5 describes the field procedure for grouting, and section 6 shows the recommended grout formulation and field testing.

2. TEST MATERIALS

In addition to the MTC grout mixture, the materials used in the test program included Type 10 cement, silica fume, flyash, latex, superplasticizer, uncoated and coated aluminum powder, calcium nitrite, and four commercial grout admixtures. The background of some of these test materials is briefly described below.

2.1 Silica fume

Silica fume is a byproduct formed during the production of silicon metal and ferrosilicon alloy. It consists of fine glassy spheres having a specific surface area of about 20,000 sq.m/Kg compared to that of 300 to 400 sq.m/Kg for normal portland cement. The physical and chemical properties of silica fume are described in References 2 and 3.

The effect of silica fume on properties of concrete has been studied (4-9). In these investigations, silica fume was either used as a partial replacement of cement (up to 40 % by mass) or as an additive to cement (up to 20 % by mass). The general conclusions were:

1. For a given workablility, concrete containing silica fume required higher water content compared to concrete without silica fume. However, the amount of mixing water could be reduced by adding superplasticizer.

2. Concrete containing silica fume had higher compressive strength, higher electrical resistivity, lower permeability, lower chloride diffusion, and better frost resistance than concrete without silica fume.

The use of silica fume in grouts has also been investigated (1,10,11). In these studies, silica fume was used as a partial replacement of cement ranging from 5 to 20 %. The findings of these studies were:

1. Silica fume significantly reduced bleeding and segregation in normal portland cement grout.

2. Silica fume grout had much higher viscosity than normal portland cement grout. Superplasticizer could be used in the silica fume grout to maintain adequate fluidity.

3. Silica fume grout exhibited thixotropic properties.

4. Silica fume grout had higher compressive strength, lower porosity and finer pore size distribution, and lower chloride permeability than normal portland cement grout.

5. Silica fume might cause handling problem because of the extreme fineness of silica fume particles.

According to the above findings, the use of silica fume in grout appears to be promising if the handling problem can be solved. In addition to low chloride permeability, the compact pore structure of silica fume grout would result in high electrical resistivity and hence offer good corrosion protection for the embedded prestressing tendons. There is little information, however, on electrical resistivity and corrosion measurement of silica fume grout in the literature.

2.2 Flyash

Flyash is the residue from the combustion of powdered coal. It consists of glassy spheres having a specific surface area of 400 to 700 sq.m/Kg.

In practical applications, flyash has been used in concrete to partially replace the cement. Concrete containing flyash has relatively high compressive strength and low permeability compared to portland cement concrete (12).

The use of flyash in grout has been reported (13). The test grouts consisted of Type 10 cement, sand, flyash and different plasticizing agents. Test results showed that there were bleeding and segregation in many of the grouts. The effect of flyash on pure cement grout is not known.

2.3 Latex

Latex is a water emulsion of a synthetic rubber obtained by polymerization. The common types of polymer latex used in concrete include styrene-butadiene rubber, polyacrylic ester, and polyvinyl acetate latex.

Latex reduces the porosity of the portland cement paste and develops strong bonds between cement hydrates and aggregates. It increases tensile strength, decreases permeability, and improves freeze-thaw resistance of portland cement concrete (14). In concrete the desirable properties attributed to latex are enhanced if the concrete is allowed to partially dry.

Test results from studies (1,13) on grouts containing latex indicated that:

1. After one year of testing, grouts containing latex showed the least horizontal shrinkage among different types of grouts tested.
2. Latex and superplasticizer appeared not to be a good combination in grout mixes. Many of these grouts exhibited bleeding and segregation.
3. Grout containing latex had low compressive strength.
4. Equipment was difficult to clean after mixing.

2.4 Aluminum powder

Aluminum powder reacts with alkalis in the cement to release hydrogen gas and is used to offset volume changes caused by settlement of cementitious materials and plastic shrinkage of the grout.

Two types of aluminum powder, uncoated and coated, are available for use. The uncoated aluminum powder is a fine powder and produces a faster reaction compared to the coated aluminum powder, which may be covered with a slowly dissolving water soluble resin to retard the expansion (15).

2.5 Calcium nitrite

Calcium nitrite has been used as a corrosion inhibitor for steel embedded in concrete and mortar in a number of studies (16-24). Based on the test results of these investigations, calcium nitrite shows promising inhibitory property. However, little published information is available on the use of calcium nitrite in grout.

3. TEST PROGRAM

3.1 Initial screening stage

The test program consisted of an initial screening stage and a final evaluation stage.

In the initial stage, grouts made with different formulations, including the MTC control, were subject to the following tests:

1. Flow time (ASTM C939)
2. Expansion (ASTM C940)
3. Bleeding (Balloon Test and ASTM C940)
4. Viscosity (ASTM D4016)
5. Compressive strength (ASTM C942)
6. Absorption and density (ASTM C642)
7. pH (pH indicating papers)

The mixer arrangement and mixing procedure were similar to that described in ASTM C938. Liquid ingredients were initially placed in the mixer and dry ingredients were charged into the mixer during the first 2 minutes of mixing. The grout was then mixed for a further 3 minutes giving a total mixing time of 5 minutes.

Test 1 was performed immediately after the grout was discharged from the mixer, and 800 ml of the grout was then filled in a graduated cylinder for Tests 2 and 3. After remixing for one minute, the grout was filled in the balloons for Test 3. It was then re-mixed for an additional one minute and 50 mm cubes were cast for Tests 5, 6, and 7. Because of the time delay caused by the above a new batch of grout was mixed for Test 4 and viscosity measurements started one minute after the standard 5 minutes of mixing.

Most of the grouts were proportioned so that their flow time was in the range from 12 to 15 seconds.

Tests for expansion were discontinued 3 hours after the initial readings. An uncoated aluminum powder was used for all the mixes in this initial stage.

Balloons used for the bleeding test were unlubricated condoms. For each test, a balloon was filled with about 500 ml of grout and was visually examined for bleeding 24 hours after casting. Bleeding was detected by the presence of voids or honeycombs on the balloon surface. When severe bleeding occurred the bleed water paths could be easily seen on the sides of the balloon. In addition to the balloon test, bleeding in the first 3 hours was also examined by the graduated cylinder test.

A Brookfield viscometer (Model# HBT) was used for viscosity measurements. For comparison purpose, the same spindle (No. 1) and rotating speed (2.5 rpm) were used for all the measurements.

Absorption and density were determined from the 50 mm cubes at the age of 28 days. Because the grouts cracked when drying, the oven-dried weights of the 50 mm cubes were determined after the submerged weights and saturated surface-dry weights were recorded.

The pH levels were measured from the saturated surface-dry cubes at the age of 28 days. The cubes were broken open and the pH was measured by pH indicating papers.

Table 1 summarizes the mix ingredients for the test grouts.

3.2 Final evaluation stage

In the final evaluation stage, the MTC control and two other grouts with apparently desirable properties were further subject to the following tests:

1. Electrical resistivity
2. Chloride permeability
3. Corrosion susceptibility

After the above tests were performed, the grout with the most desirable properties was subject to a compressive strength and an expansion test in order to examine the use of coated aluminum powder in grout and the effectiveness of aluminum powder on expansion with time.

3.2.1 Electrical resistivity

Electrical resistivities of the grouts were determined from 62x200x200 mm slabs (Figure 1). Each slab contained two 12 mm diameter mild steel rods, which were centred at 31 mm from the top surface and were placed 100 mm apart. The rods were machine-polished and were embedded 175 mm in the slab. The protruding ends and the adjacent 37 mm embedded lengths of the rods were coated with both epoxy primer and epoxy paint in order to prevent corrosion at these areas. The forms for the slabs were made with rigid plywood and heavy steel cover plates so that expansion of the fresh grouts was fully restrained. One slab was cast for each test grouts.

AC electrical resistances between the rods in the saturated surface-dry slabs were measured at the ages of 3, 7, 14, 21, and 28 days. These resistance readings were subsequently converted to electrical resistivities by a calibration factor (25), which was found experimentally to be 15 ohm-cm/ohm. All the slabs were stored in a saturated lime solution during the entire test period.

3.2.2 Chloride permeability

Cylinders were cast from the MTC control and two other grouts, and at the age of 90 days these cylinders were shipped in saturated condition to the MTC laboratories in Downsview. During testing, three slices were cut from each cylinder and tested for chloride permeability in accordance with AASHTO Designation: T227-831, Interim Method of Test for Rapid Determination of the Chloride Permability of Concrete.

3.2.3 Corrosion susceptibility

After the electrical resistivity measurement in Section 3.2.1 was completed, the slabs were stored in a 3.5 % NaCl solution. At the age of 200 days, the electrical resistivities of the grouts were measured. Each slab was subsequently placed on the surface of an external cathode, which consisted of a 400x50x3 mm mild steel plate and two 12 mm diameter mild steel rods (Figure 2). The bottom 20 mm of the slab and the entire steel plate were submerged in an aerated lime water to ensure good electrical contact between the slab and the plate. The potential difference between the embedded steel and the cathode was measured 5 minutes after bottom of the slab and the plate had been submerged in the lime water. When the potential measurement was completed, the steel was electrically coupled to the cathode and corrosion current was determined by measuring the current flow between the steel and the cathode 5 minutes after the electrical connection was made. Figure 3 shows the test arrangement for the corrosion measurement.

3.2.4 Strength and expansion

Two grout samples were prepared from the selected grout formulation. The difference in these two samples was only the type of aluminum powder used in the mix. Sample A contained the uncoated aluminum powder used in the foregoing tests, and sample B contained a coated aluminum powder.

In the compressive strength test, six 50 mm cubes were made from each grout samples. The cubes were tested at 7 days and 28 days.

In the expansion test, the dry ingredients for five 1.5 Kg batches were made from each grout samples. These dry ingredients were individually placed in ten 5-litre plastic dessicators and were well mixed by hand for 5 minutes. Expansion tests on the wet grouts of samples A and B were performed immediately after mixing, and at 7 days, 14 days, 28 days, and 56 days. With the exception of the ones that were tested after mixing, all the dry ingredient samples were stored in the open dessicators in a storage room at about 23 C before testing.

4. RESULTS AND DISCUSSION

4.1 Initial screening stage

4.1.1 MTC mixes

A total of 6 MTC mixes were made in this series. The test results for these mixes are listed in Appendix A. It should be noted that water reducing agent Porzite L73 (liquid) was used in all the mixes rather than Porzite 73 (powder).

When the water/cement ratios of the mixes were between 0.47 and 0.50, the dosage of aluminum powder was 0.0067 % and that of water reducing agent was between 0.40 % and 0.47 % by mass of cement, the flow time, expansion, bleeding, and compressive strength all satisfied the MTC requirement.

The mix with water/cement ratio of 0.48 (MTC6) was chosen as the control mix. The flow rate for this mix was between 13 and 14 seconds and the expansion was 8 %. There was very little bleeding and no segregation or plastic shrinkage was observed.

The 7-day and 28-day compressive strengths for the control were 39 MPa and 44 MPa, respectively. Absorption after immersion was 30 % and bulk density after immersion was 1.83. The pH was in the range from 12.5 to 13.5, which is the typical pH value for cement paste.

Viscosity of the control increased substantially with time. For instance, the viscosity increased from the initial value of about 10,000 cps to 25,000 cps in 6 minutes (Figure 4). If the mix was left to stand for 20 minutes after the 5-minute mixing period the flow rate tripled. However, continual mixing during this 20-minute period resulted in only about a one second increase in flow time. Nevertheless, the rapid increase in viscosity with the MTC mix during rest periods may be a cause of concern in field applications.

Although the 3-hour expansion was 8 %, approximately 90 % of the expansion occurred within the first 30 minutes and the expansion was negligible after 1 hour.

4.1.2 Silica fume (SF) mixes

Three different dosages of silica fume, 5 %, 10 %, and 15 % as replacement of cement, were used in the silica fume mixes. A total of 11 mixes were made in this series (Appendix B).

It was hoped that the use of aluminum powder could be eliminated from these mixes but plastic shrinkage was observed in the mixes without aluminum powder. Aluminum powder, therefore, was added to the remaining mixes to offset plastic shrinkage.

For the 3 dosages of silica fume used, when the water/cementitious material ratios were between 0.33 and 0.36, the dosage of aluminum powder was 0.0067 % and that of superplasticizer Melment F10 was 1 % by mass of cementitious materials (cement and silica fume), the flow rate, expansion, bleeding, and compressive strength all satisfied the MTC requirement.

The mixes with water/cementitious material ratio of 0.33, SF-A4 (5 % silica fume), SF-B1 (10 % silica fume), and SF-C1 (15 % silica fume), were chosen as the representative mixes. The flow time and expansion of these mixes were comparable to those of the control. There was little bleeding in SF-A4 and there was no bleeding in both SF-B1 and SF-C1.

Compared to that of the control, the initial viscosity of SF-A4 and SF-B1 was lower and viscosity of all the 3 mixes increased more gradually with time (Figure 4). For example, the time required for the viscosity of SF-A4, SF-B1, and SF-C1 to reach 25,000 cps from the initial values was approximately 6 times, 4 times, and 2 times longer, respectively, than that of the control.

All the silica fume mixes were thixotropic. For instance, SF-C1 became gel when it was left in a beaker for one hour, but it regained plasticity when the beaker was shaken moderately. The same finding has also been reported in other studies (10,11). Because of its thixotropic property, the SF grout would likely be pumpable in the field even though it had been left to stand for a short period of time.

Compressive strength for these mixes was considerably higher than that of the control at all ages. At 28 days, the strength for the 3 mixes was from 30 % to 40 % higher than that for the control (Figure 5).

For the 3 selected mixes, it appeared that there existed a critical level of silica fume dosage above which the effect of silica fume on compressive strength was small. As shown in Figure 6, the 28-day strength increased about 6 % when the silica fume content increased from 5 % to 10 %, and the strength changed little when the silica fume content increased from 10 % to 15 %.

Absorption of these mixes was about 20 %, which was approximately two-thirds of that of the control. This lower absorption value might be partly attributed to the lower water content in the mixes.

Bulk density for these mixes was about 1.96, which was approximately 7 % higher than that for the control. The higher density implied that these mixes had a more compact pore structure. This was confirmed by visual inspection of the 50 mm cubes after they were broken open. Generally the cubes containing silica fume were less porous than the MTC cubes.

The pH for these mixes, similar to that for the control, was between 12.5 and 13.5. The addition of silica fume did not appear to have a significant effect on the pH.

Expansion in these mixes was comparable to that in the control and also occurred mostly during the first 30 minutes.

4.1.3 Calcium nitrite (CN) mixes

Calcium nitrite powder, containing 90 % calcium nitrite, was added to the control and two silica fume mixes, SF-A4 (5 % silica fume) and SF-B1 (10 % silica fume). A total of 4 mixes were made in this series (Appendix C).

An addition of 0.5 % calcium nitrite powder by mass of cement in the control resulted in small changes in flow time and viscosity (Figure 7). Bleeding increased noticeably and was about 1.5 % of the total mass. Expansion decreased from 8 % to about 2 %.

The 28-day strength of the control increased about 12 % with 0.5 % calcium nitrite powder. Bulk density increased slightly but absorption and pH remained about the same.

When a dosage of 0.5 % calcium nitrite powder by mass of cementitious materials was added in SF-A4, there was little bleeding and no segregation was observed. When the same amount of calcium nitrite powder was added in SF-B1, no bleeding and segregation were seen. Expansion in both mixes, again, decreased to about 2 %.

With 0.5 % calcium nitrite powder, both the silica fume mixes had a higher initial viscosity value, but viscosity increased relatively slowly with time compared to that of SF-B1 and SF-A4 (Figures 4 and 7). The rate of increase in viscosity was markedly reduced for the mix containing 5 % silica fume; the time required for the viscosity of this mix to reach 25,000 cps was double that of SF-A4. On the other hand, as shown in Figure 7, when 1 % calcium nitrite powder was added, the viscosity increased much more rapidly.

Compressive strength for both the silica fume mixes increased considerably when calcium nitrite powder was added to the mixes. The addition of 0.5 % calcium nitrite resulted in about 25 % increase in the 28-day strength. Absorption and bulk density of both mixes also increased by about 5 % when 0.5 % calcium nitrite was added. The pH of the mixes, however, remained about the same.

A small amount of plastic shrinkage was evident in all the mixes and this might be a cause of concern. It might be possible to offset the plastic shrinkage by increasing the dosage of aluminum powder; however, the use of aluminum powder is felt to be generally undesirable and any increased dosage and additional reliance on aluminum powder should be avoided if possible.

The addition of calcium nitrite seemed to make the grouts more brittle. The corners of the 50 mm cubes were chipped quite easily when demoulding.

Since it is brittle and has tendency to shrink, the calcium nitrite mix was not considered a viable alternative.

4.1.4 Latex (LA) mixes

A Styrene-Butadiene Rubber (SBR) type latex containing 48 % by mass latex solids was used in all the LA mixes. It was added to the mixes at 15 % by mass latex solid/cement ratio. A total of 6 mixes were made in this series (Appendix D).

The addition of a superplasticizer (1 % by mass of cement) had only a small effect on flow time and made the grout foamy. Also, it was difficult to dissolve the superplasticizer in the latex directly; hence, the superplasticizer was dissolved in water

before mixing with the latex. The combination of latex and superplasticizer did not appear to be desirable.

The latex acted as a plasticizing agent and low water/cement ratios could be obtained at reasonable flow time without an addition of a superplasticizing agent. For the mixes without superplasticizer, when the water/cement ratios were between 0.30 and 0.35 and aluminum powder dosage was 0.0067 %, the flow times were in the range from 13 to 17 seconds. At these water/cement ratios, there was little bleeding and no segregation was observed. Expansion was about the same as that in the control.

Viscosity of these mixes increased more gradually with time than that of the control. For the mix with water/cement ratio of 0.30 (LA5), although the initial viscosity was higher than that of the control, the time required for viscosity to reach 25,000 cps from the initial value was about 30 % longer (Figure 4).

Absorption of LA5 was 17 %, which was about 60 % of that of the control. Bulk density was 1.79, which was slightly lower than of the control. The pH was in the range from 12.5 to 13.5 and was similar to the control.

Compressive strength for the LA5 was considerably lower than that for the control. The 28-day strength for LA5 was 29 MPa, which was only about 80 % of the MTC requirement of 35 MPa. This was partly because the grouts were tested under a saturated surface-dry condition. It is known that latex modified concretes require a modest degree of drying in order to develop their full potential. In field applications, drying in a post-tensioning duct is unlikely and as a result latex modified grouts may not be able to develop adequate strength under such a condition.

It was found that the mixing equipment had to be cleaned quickly before the latex began to dry out. Once the latex was set, a rubber-like layer would adhere to the equipment surface and was difficult to remove.

Because of its low strength, the latex mix was not considered a viable option.

4.1.5 Flyash (FA) mixes

Lakeview flyash was used in all the FA mixes and the dosage was 30 % as replacement of cement. In these mixes, water/cementitious material ratio and superplasticizer dosage varied while aluminum powder dosage remained at 0.0067 %. A total of 3 mixes were made in this series (Appendix E).

With water/cementitious material ratio of 0.33 and 3 % superplasticizer by mass of cementitious materials, the mix was thick and the flow time was 41 seconds. Bleeding was severe and was more than 10 % of the total mass. Bleed water paths were clearly seen on the sides of the balloons and the grout had not fully set 24 hours after casting. Segregation was evident and the flyash tended to settle at the lower parts of the balloons and the 50 mm cubes.

When the superplasticizer dosage was increased from 3% to 4 %, the flow time changed little and, similar to the first mix, segregation and severe bleeding occurred.

At water/cementitious material ratio of 0.45 and 1 % superplasticizer, the flow time was reduced to 12 seconds and, again, segregation and severe bleeding occurred. Viscosity of this mix increased relatively slowly compared to the control. The 28-day strength was about 80 % of that of the control but met the MTC requirement. The absorption, bulk density, and pH were similar to those of the control.

Because of the segregation and severe bleeding, the combination of Type 10 cement, flyash, and superplasticizer did not appear promising.

4.1.6 Proprietary grouting admixtures (PROP)

Four samples of proprietary grouting admixtures: PROP-A, PROP-B, PROP-C, and PROP-D were examined.

PROP-A mixes: PROP-A is a non-expansive grout which contains both cementitious materials and admixtures. Only water is required to be added in an amount that produces a flow of more than 20 seconds as recommended by the manufacturer. A total of 3 mixes were made in this series (Appendix F).

When water/solid material ratios of 0.35 or more were used, the flow time was less than 20 seconds; segregation and bleeding occurred. At water/solid material ratio of 0.33, the flow rate was about 23 seconds; bleeding was negligible and no segregation occurred. These results confirmed the manufacturer's claim.

Viscosity of the mix with water/solid material ratio of 0.33 (PROP-A1) was comparable to that of the control (Figure 4). This mix thickened quickly. It set in about 40 minutes and would not regain plasticity upon remixing. After being left in a graduated cylinder for one hour, the mix was hardened and was difficult to remove. The heat generated by the grout could be felt on the side of the cylinder.

The 7-day and 28-day strengths for PROP-A1 were about 60 % higher than those for the control and were comparable to those for CN1 (water/cementitious material ratio of 0.33, 10 % silica fume and 0.5 % calcium nitrite powder).

Absorption of PROP-A1 was about 75 % of that of the control and bulk density was about 13 % higher. The pH, similar to other mixes, was between 12.5 and 13.5.

There was no expansion in the grout. A small amount of plastic shrinkage was seen and this might be a cause of concern.

Because of its fast-setting characteristics, the PROP-A grout may be only suitable for use under low temperature conditions in which the setting time of the grout can be retarded.

PROP-B mixes: PROP-B is a grouting admixture which acts as both a superplasticizing and expanding agent. The recommended dosage is 1 % by mass of cement.

A total of 4 mixes were made in this series (Appendix F). One percent PROP-B by mass of cementitious materials was added to a mix with Type 30 cement, a mix with Type 10 cement, and 2 mixes with Type 10 cement and 10 % silica fume (as replacement of cement).

When the water reducing agent and aluminum powder in the control were replaced by 1 % PROP-B, the flow time changed little, and the rate of increase in viscosity was lower although the mix still thickened quite quickly. Bleeding increased noticeably. Expansion was 11 % and increased more gradually with time. The expansion continued for up to 2 hours with approximately 90 % of the expansion occurring in the first 60 minutes.

Compressive strength for this mix was lower than that for the control, and the 28-day strength was only about 72 % of the MTC requirement. The absorption, bulk density, and pH were similar to those of the control.

Because of the low strength, bleeding, and thickening characteristics, Type 30 cement and PROP-B did not appear to be a good combination.

When 1 % PROP-B was added to Type 10 cement, at water/cement ratio of 0.38, the flow time was similar to that of the control, but viscosity increased more gradually with time and was comparable to that of SF-A4. Bleeding occurred and was about 1.5 % of the total mass. Expansion was 15 % and most of the expansion occurred in the first 60 minutes.

The 7-day and 28-day strengths of this mix were 30 MPa and 36 MPa, respectively, which were lower than those for the control but met the MTC requirement. While the absorption was about 80 % of that of the control, the bulk density and pH were similar to those of the control.

When 1 % PROP-B was added to Type 10 cement and 10 % silica fume, at water/cementitious material ratio of 0.40, the flow time of the mix was comparable to the control. There was no bleeding or segregation in this mix (PROP-B4). Viscosity was high initially and was about 2 times that of the control, but it increased more gradually with time and the time required to reach the reference viscosity value of 25,000 cps was about the same for both mixes.

Expansion in PROP-B4 was 14 % and, similar to the other PROP-B mixes, occurred mostly within the first 60 minutes.

At 28 days, the strength for PROP-B4 was 32 MPa, which was below the MTC requirement and was only about 60 % of that for the 10 % silica fume mix with similar flow time (SF-B1).

It was found that the sides of the 50 mm cubes were chippy and there were small voids on the surfaces.

The combination of Type 10 cement and PROP-B appeared to perform better than that of Type 30 cement and PROP-B; however, the bleeding in the grout was the major concern. The combination of Type 10 cement, silica fume and PROP-A also did not appear to be promising because of the low strength.

PROP-C mixes: PROP-C is a grouting admixture which contains expanding, fluidifying, and water reducing agents. The suggested dosage is 1 % by mass of cementitious materials.

A total of 2 mixes were made in this series (Appendix F). One percent PROP-C by mass of cement was added to Type 10 cement with water/cement ratios of 0.40 and 0.45.

The flow time of the mix with water/cement ratio of 0.40 was between 14 and 15 seconds. Viscosity of this mix (PROP-C1) increased substantially with time and was comparable to that of the control. There was negligible bleeding and no segregation was observed.

Expansion was larger and lasted longer than that in the other mixes tested. It started to level off after 5 hours. The 1-hour, 2-hour, and 3-hour expansions were about 10, 17, and 21 %, respectively.

Absorption of PROP-C1 was 25 %, about 85 % of the control. Bulk density was 1.97 and was similar to the 3 selected silica fume mixes (SF-A4, SF-B1 and SF-C1).

At 28 days, the strength for PROP-C1 was 29 MPa, only about 85 % of the MTC requirement. The low strength of this mix was the major concern.

PROP-D mixes: PROP-D is an non-expansive admixture containing silica fume. The recommended dosage is about 17 % as replacement of cement.

In this series, the suggested dosage of the admixture was added to Type 10 cement with different water/cementitious material ratios. A total of 3 mixes were made in this series (Appendix F).

When water/cementitious material ratio of 0.60 or less was used, the mix was too thick and could not be mixed properly in the mixer. At water/cementitious material ratio of 0.68, the flow time of the mix was about 15 seconds. There was negligible bleeding and no segregation was seen.

The viscosity of the grout increased rapidly and the rate of increase in viscosity was higher than that of the control.

Plastic shrinkage occurred. Large shrinkage cracks were seen on the sides of the 50 mm cubes.

At 28 days, the strength for the mix was 33 MPa, slightly below the MTC requirement.

Absorption of the mix was 54 %, which was the highest among all the test grouts. The high absorption was mainly due to the high water content in the mix. Bulk density was 1.67 and the pH was between 12.5 and 13.5.

Because of the shrinkage, low strength, and fast-thickening characteristics, this grout was not considered a viable option.

4.1.7 Summary

The foregoing test results indicated that the two silica fume mixes, SF-B1 (10 % silica fume) and SF-C1 (15 % silica fume) appeared to be the most promising. Consequently, these two mixes, along with the MTC control, were subject to further tests in the final evaluation stage. Table 2 summarizes the test results for the control and the two selected silica fume mixes.

It should be noted that the expansion in these mixes occurred mostly within 30 minutes after mixing. Hence, when the uncoated aluminum powder is used in field applications, the grouting operation should be completed 15 to 20 minutes after mixing to ensure that a positive expansion is developed in the cable duct.

4.2 Final evaluation stage

4.2.1 Electrical resisitivity

Figure 8 shows the electrical resistivities for the control and the two silica fume mixes SF-B1 (10 % silica fume) and SF-C1 (15 % silica fume) from 3 days to 28 days.

Among these test grouts, the control had the lowest resistivity at all ages. The resistivity for this mix increased slowly initially and changed little after 14 days. At 28 days, the resistivity was 1700 ohm-cm, which was only 17 % of the suggested resistivity threshold value for corrosion prevention (26,27). According to these references, corrosion of depassivated embedded steel in concrete would occur if electrical resistivity of the concrete is below a threshold value of 10,000 ohm-cm and both oxygen and moisture are present. The low resistivity for the control was partly due to the relatively high water content in the mix (water/cement ratio 0.48).

Resistivity for SF-C1 was the highest among the three test grouts and increased most rapidly during the test period. At 28 days, it was 56,000 ohm-cm, which was about 34 times that of the control and was more than 5.5 times the probable resistivity threshold value.

Resistivity for SF-B1 at 28 days was 37,000 ohm-cm, which was approximately 22 times that of the control and was more than 3.5 times the probable resistivity threshold value.

Clearly, resistivity increased with increase in silica fume content in the mixes. For the two silica fume mixes, an increase in silica fume content from 10 % to 15 % resulted in about 50 % increase in resistivity at 28 days.

The high resistivity for the silica fume mixes probably resulted from the dense pore structures of these grouts. Silica fume consists of very fine vitreous particles which are about 50 to 100 times finer than average cement particles.

4.2.2 Chloride permeability

Table 3 shows the test results of the chloride permeability measurement for the control and the two silica fume mixes. The charge (in Coulombs) obtained for each sample slices and the average charge are given in the table.

AASHTO T227-831 provides an interpretation of the results for concrete samples which would normally be expected to have a paste content of 30 % 5 %. Consequently, the samples tested in this program, which were 100 % paste would exhibit a permeability about 100/3 = 3.3 times that of the equivalent quality of concrete. The average 'concrete equivalent'permeabilities of the grout samples have been calculated by dividing the actual average values by 3.3 and these results are given at the bottom of Table 3.

In two of the three tests on the control MTC grout, it was necessary to stop the test because of the high temperatures generated. This indicated that the grout had high chloride permeability. A similar finding has been previously reported (1).

AASHTO T227-831 suggests that the values of 100 to 1000 coulombs indicate very low chloride permeability such as from latex modified or internally sealed concrete. Since the 'concrete equivalent' charge values for the two silica fume mixes were about 100 to 200, these two mixes had very low chloride permeabilities.

4.2.3 Corrosion susceptibility

Table 4 shows the test results obtained from the corrosion measurement for the control and the two silica fume mixes. The corrosion current and potential difference data were the average values of the two steel samples embedded in each slab.

Clearly, the 15 % silica fume mix (SF-C1) provided the best corrosion protection for the embedded steel among the three test grouts. The average corrosion current of the steel in this grout was only about 8 % of that of the steel in the control.

The 10 % silica fume mix (SF-B1) also provided better corrosion protection for the embedded steel than the control. The average corrosion current of steel in this grout was about 20% of that of the steel in the control.

The low corrosion currents in the two silica fume grouts was probably due to the relatively high resistivities and low chloride permeabilities of these mixes compared to that of the control.

Note that the measured corrosion current showed only the macrocell corrosion rate of the embedded steel with respect to the cathode and did not indicate the self-corrosion along the steel. A test was performed to examine the self-corrosion along the embedded steel in the saturated MTC control slab using AC impedance technique. The test result showed that the corrosion rate was negilgible perhaps due to a lack of dissolved oxygen in the saturated slab.

4.2.4 Strength and expansion

The above test results indicated that both the silica fume mixes, SF-B1 (10 % silica fume) and SF-C1 (15 % silica fume), were promising. Only the SF-B1 mix was used to examine the use of coated aluminum powder in grout and the relationship between time and expansion caused by uncoated and coated aluminum powder. Two samples of SF-B1 were prepared. Sample A contained the uncoated aluminum powder used in the previous tests and sample B contained a coated aluminum powder. The dosage of aluminum powder in both samples was the same as that in the previous tests (0.0067 % by mass of cement).

Table 5 shows the test results for the strength and expansion tests. As shown in the table, the strengths for sample A and sample B were comparable.

It was observed that sample A had a smoother appearance than sample B. While there was no bleeding in sample A, there was a negligible amount of bleed water in sample B at the end of the 3-hour expansion period. The amount of bleed water in sample B appeared to increase somewhat after the grout had been left in the graduated cylinder for 5 hours. A small amount of bleeding was also evident when the 50 mm cubes were removed from the forms 24 hours after casting.

Compared to the expansion in sample A, the expansion in sample B was more gradual and occurred mostly in 60 minutes, which was twice as long as that in sample A. However, the total expansion in sample B was only about 70 % of that in sample A.

The expansion in both samples decreased with increase in storage time. The expansion in the 2-week old grout samples and 4-week old grout samples was about 90 % and 60 %, respectively, of that in the samples tested immediately after mixing. The expansion in the 8-week old samples was about the same as that in the 4-week old samples.

The fluidity of both samples also decreased with increase in storage time. The flow time for the 2-week old samples and 4-week old samples were approximately 2 and 4 times, respectively, that of the samples tested immediately after mixing.

The decrease in expansion and fluidity of the samples was probably due to the absorption of moisture by the aluminum powder and superplasticizer from the air.

It should be noted that the storage condition in this study represented a 'severe' storage condition. If the dry mixtures were stored in sealed packages, the decrease in expansion and fluidity of the grout samples would likely be less since the moisture from the air could not easily reached the dry mixtures. Nevertheless, the effectiveness of aluminum powder and superplasticizer with time must be considered if prepacking and prolonged storage of the above grout mixtures is used for field applications.

4.2.5 General observation

Among the various types of grout formulations tested in this program, the most promising grout formulation was the combination of Type 10 cement, 10 % to 15 % silica fume

as replacement of cement, 1 % Melment F10 and 0.0067 % aluminum powder by mass of cementitious materials, with water/cementitious material ratio of 0.33.

When the uncoated aluminum powder was used, the expansion in the mix occurred mostly within 30 minutes after mixing. This expansion period was extended to about 60 minutes when the coated aluminum powder was used. However, the appearance of the grout containing the coated aluminum powder appeared to be a little coarser and exhibited a small amount of bleeding.

The above mix was proportioned to obtain a flow time of 12 to 15 seconds. It was noted that the grout was still flowable and pumpable when its flow time was between 20 and 30 seconds.

Prepacking of the dry ingredients of the grout seems to be a good alternative for field applications. It can eliminate the handling problems of silica fume, aluminum powder and powdered superplasticizer and ensure a strict quality control. However, caution must be exercised. The mixture should be stored in dry condition and the storage time should be as short as possible.

5. FIELD PROCEDURES

Present field procedures used to grout prestressing cable ducts were observed on October 30, 1986. In general these procedures probably cannot be changed drastically without interfering with the orderly progress of the work. p. One crew member loaded four bags of cement into the mixing portion of the grout pump, added an approximate measure of premixed aluminum powder and powdered water reducing admixture and then the crew chief added water by pail until the consistency appeared suitable by visual observation. After 2 or 3 minutes mixing the grout was pumped into the ready use tank from where it was pumped into the cable ducts. It is estimated that the grout was in place in the ducts within about a 15 minute period after the first addition of water to the cement. The progress of duct filling was observed first at the central riser (of the two span structure observed) which was folded and tied with baling wire when grout began to emerge from the riser and then at the far end of the duct which was similarly tied when grout emerged.

The main area of concern with the above procedure is in the quality control aspects of the operation. No attempt seemed to be made to control the exact amount of added mixing water or powdered additive and leakage was observed through the tied off ends of the duct filling tubes for a few minutes in some instances. This section of the report contains recommendations to hopefully improve these aspects.

It is imperative that the flow time of the grout be measured and an adjustable constant volume container be then used to accurately maintain the water content at the quantity necessary to give the desired flow time. Field measurement of the flow time is, therefore, required by the inspector at suitable intervals and adjustments made to the constant volume container when required. This is the only quality control test deemed feasible. It would serve no purpose to perform tests on the hardened grout. This is because the grout cannot be removed and replaced once it has hardened in the cable duct regardless of the results of subsequent tests.

Preblending of the cement with the other additives (silica fume, powdered superplasticizer and aluminum powder) and bagging this mixture for use in each job will ensure the correct amount of additive is used at all times.

Some more efficient hose clamping method using, perhaps, mechanical clamps, instead of baling wire, for clamping the various risers and duct filling pipes should be used to

maintain a tight seal until the grout has reached its initial set. This will enable the gaseous expansion produced by the aluminum powder to develop some small positive pressure and ensure intimate contact between the grout, cable and duct at all locations along the cable length.

6. RECOMMENDATION

Based on the test results in this investigation, the recommended grout formulation is the combination of Type 10 cement, 10 to 15 % silica fume as replacement of cement, 1 % Melment F10 and 0.0067 % uncoated aluminum powder by mass of the cementitious materials (cement and silica fume), with water/cementitious material ratio of 0.33.

The dry ingredients of this grout may be premixed and bagged before use in the field to ensure good quality control and avoid handling problems of the powdered additives (silica fume, aluminum powder, and superplasticizer). It should be packed in sealed and water-proof bags to maintain the effectiveness of the aluminum powder and superplasticizer. The bags containing the dry mixture should be stored under dry conditions and the storage time should be as short as possible.

With the uncoated aluminum powder used in this study, the expansion of the grout will be essentially completed 30 minutes after mixing. Therefore, the grouting operation should be completed within 20 minutes after mixing so that a positive expansion can be developed in the cable duct.

The uncoated aluminum powder in the above mix may be replaced by a coated aluminum powder to prolong the expansion time of the grout provided that the coated aluminum powder does not induce bleeding in the grout and the grout meets all the other test requirements. Further studies can be performed on the use of other commercially available coated aluminum powder in the above mix.

Flow time of the grout may be measured in the field as a quality control test. When the preblended dry mixture is used, the flow time of the grout may increase depending on the duration of the storage time of the dry mixture. In addition to the minimum flow time of 12 seconds, the allowable maxiumum flow time should be limited to 20 seconds or less to ensure that there is no problem in pumping.

A field trial of the recommended grout should be performed to examine the feasibility of this grout for field applications.

References

1. Trebish, J.R., "Evaluation of Grout Mixtures for Post Tension Bridges," Report 3A, Research and Development Branch, Ministry of Transportation and Communications, 1985, 57 pp.

2. "Condensed Silica Fume," University of Sherbrooke Publications, Quebec, 1983, 52 pp.

3. Malhotra, V.M., and Carette, G.G., "Silica Fume Concrete - Properties, Applications and Limitations," Paper presented at the Annual Meeting of the Institute of Concrete Technology, Fulmer Grange, Slough, England, June 1982, 23 pp.

4. Sellevold E.J., and Radjy, F.F., "Condensed Silica Fume (Microsilica) in Concrete: Water Demand and Strength Development," ACI SP-79, American Concrete Institute, 1983, pp. 677-694.

5. Gjorv, O.E., "Durability of Concrete Containing Condensed Silica Fume," ACI SP-79, American Concrete Institute, 1983, pp. 695-708.

6. Sorensen, E.V., "Freezing and Thawing Resistance of Condensed Silica Fume (Microsilica) Concrete Exposed to Deicing Chemicals," ACI SP-79, American Concrete Institute, 1983, pp. 709-718.

7. Vennesland, O., and Gjorv, O.E., "Silica Concrete - Protection Against Corrosion of Embedded Steel," ACI SP-79, 1983, pp. 719-729.

8. Fischer, K.P., Bryhn, O., and Aagaard, P., "Corrosion of Steel in Concrete: Some Fundamental Aspects of Concrete with Added Silica," Corrosion, National Association of Corrosion Engineers, 1984, pp. 358-366.

9. Marusin, S.L., "Chloride Ion Penetration in Conventional Concrete and Concrete Containing Condensed Silica Fume," ACI SP 91, American Concrete Institute, 1986, pp. 1119 - 1133.

10. Aitcin, P-C., Ballivy, G., and Parizeau, R., "The Use of Condensed Silica Fume in Grouts," ACI SP-83, 1984, pp. 1-18.

11. Domone, P.L., and Tank, S.B., "Use of Condensed Silica Fume in Portland Cement Grouts," ACI SP-91, American Concrete Institute, 1986, pp. 1231-1260.

12. Mehta, P.K., "Mineral Admixtures," Chapter 6, Concrete Admixtures Handbook, V.S. Ranmachandran, ed., Noyes Publications, N.J., 1984, pp. 303-336.

13. Cheng, C.L., Griffiths, K.G., and Brodie, N.W., "Nonshrink Grout Properties," Project No. 2137-80, Research and Development, British Columbia Hydro and Power Authority, 1983, 68 pp.

14. Ohama, Y., "Polymer-Modified Mortars and Concretes," Chapter 7, Concrete Admixtures Handbook, V.S. Ramachandran, ed., Noyes Publications, N.J., 1984, pp. 337-429.

15. Mailvaganam, N.P., "Miscellaneous Admixtures," Chapter 9, Concrete Admixtures Handbook, V.S. Ramachandran, ed., Noyes Publications, N.J., 1984, pp. 480-492.

16. Rosenberg, A.M., Gaidis, J.M., Kossivas, T.G., and Previte, R.W., "Corrosion Inhibitor Formulated with Calcium Nitrite for Use in Reinforced Concrete," ASTM STP No. 629, 1977, pp.89-99.

17. Rosenberg, A.M., and Gaidis, J.M., "The Mechanism of Nitrite Inhibition of Chloride Attack on Reinforcing Steel in Alkaline Aqueous Environments," Material Performance, Vol. 18, 1979, pp.45-48.

18. Rosenberg, A.M., and Gaidis, J.M., "Methods of Determining Corrosion Susceptibility of Steel in Concrete," Transportation Research Record No. 692, 1978, pp.28-34.

19. Lundquist, J.T. Jr., Rosenberg, A.M., and Gaidis, J.M., "Corrosion Inhibitor Formulated with Calcium Nitrite for Chloride Containing Concrete - 2. Improved Electrochemical Test Procedure," Corrosion '77 - International Corrosion Forum Devoted Exclusively to the Protection and Performance of Materials, Mar. 1977, Paper 126, pp.126.1-126.13.

20. Lundquist, J.T. Jr., Rosenberg, A.M., and Gaidis, J.M., "Calcium Nitrite as an Inhibitor of Rebar Corrosion in Chloride Containing Concrete," Material Performance, Vol. 18, 1979, pp.36-40.

21. Hartt, W.H., and Rosenberg, A.M., "Influence of Ca(NO2)2 on Sea Water - Corrosion of Reinforcing Steel in Concrete," ACI STP 65-33, 1980, pp.609-615.

22. Berke, N.S., and Stark, P., "Calcium Nitrite as an Inhibitor: Evaluating and Testing for Corrosion Resistance," Concrete International, Sept. 1985, pp.42-47.

23. Berke, N.S., "The Use of Anodic Polarization to Determine the Effectiveness of Calcium Nitrite as an Anodic Inhibitor," ASTM STP 906, 1986, pp.78-91.

24. Virmani, Y.P., Clear, K.C., and Pasko, T.J., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs, V.5 - Calcium Nitrite Admixture on Epoxy-Coated Reinforcing Bars as Corrosion Protection Systems," Report No. FHWA/RD-83/012, Federal Highway Administration, Washington, D.C., Sept. 1983, 71 pp.

25. Clear, K.C., "Cost Effective Rigid Concrete Construction and Rehabilitation in Adverse Environments," FCF Annual Progress Report, Project No. 4K, 1981.

26. Brown, R.D., "Design Prediction of the Life for Reinforced Concrete in Marine and Other Chloride Environments," Durability of Building Materials, Vol. 1, 1982, pp. 113-125.

27. Hope, B.B., Ip, A.K.C., and Manning, D.G., "Corrosion and Electrical Impedance in Concrete," Cement and Concrete Research, Vol. 15, 1985, pp. 525-534.

Grout	Mix Ingredient
MTC	Type 30 cement, distilled water, porzite L73, uncoated aluminum powder
SF	Silica fume (5, 10, 15 % replacement of cement), Type 10 cement, distilled water, Melment F10, uncoated aluminum powder
CN	Calcium nitrite powder (0.5 %, 1 % by mass of cementitious materials), selected MTC and SF mixes
LA	Latex Modifier A (48 % latex solids), Type 10 cement, distilled water, Melment F10*, uncoated aluminum powder
FA	Lakeview flyash (30 % replacement of cement), Type 10 cement, distilled water, Melment F10, uncoated aluminum powder
PROP	Four samples of proprietary grout admixtures

* Melment F10 was used in 2 mixes.

Table 1. Mix ingredients for test grouts

Test		Control	SF-B1	SF-C1
Flow time (sec)		13.2	13.9	14.5
Expansion (%)		7.5	7.0	6.8
Bleeding		negligible	none	none
Viscosity	I (cps)+	10800	3750	11000
	T (min)+	6.0	20.8	10.2
Strength	7-day (MPa)	39.4	48.9	49.3
	28-day (MPa)	44.3	62.1	62.9
Absorption (%)*		29.5	20.5	20.4
Bulk density**		1.83	1.96	1.96
pH		12.5-13.5	12.5-13.5	12.5-13.5
Remarks		.thickened quickly	.smooth appearance .thixotropic	.smooth appearance .thixotropic

\+ I - Initial viscosity
T - Time required to reach a reference viscosity value of 25000 cps
* Absorption after immersion
** Bulk density after immersion

Table 2. Test result summary from initial screening stage : MTC control, 10 % silica fume (SF-B1), and 15 % silica fume (SF-C1)

	Charge (Coulombs)		
Sample	Control	SF-B1	SF-C1
#1	6912*	741	395
#2	8019**	689	373
#3	7796	676	336
Average	7576	702	368
Concrete Equivalent	2300	210	110

* Test stopped at 91 minutes due to high temperature
** Test stopped at 90 minutes due to high temperature

Table 3. Rapid chloride permeabilities of test grouts : MTC control, 10 % silica fume (SF-B1), and 15 % silica fume (SF-C1)

Mix	Electrical Resistivity (ohm-cm)	Potential Difference (mV)	Corrosion Current (uA/sq.cm)
Control	2340	440	2.9
SF-B1	37300	350	0.59
SF-C1	86500	320	0.22

Table 4. Corrosion measurements of test grouts : MTC control, 10 % silica fume (SF-B1), and 15 % silica fume (SF-C1)

Age (days)	Sample A	Sample B
	Compressive strength (MPa)	
7	40.5	39.8
28	54.7	53.2
	Expansion (%)	
0	8.0	5.7
7	7.6	4.9
14	7.4	5.0
28	4.6	3.3

Table 5. Strength and expansion of 10 % silica fume mix : Sample A (with an uncoated aluminum powder) and sample B (with a coated aluminum powder)

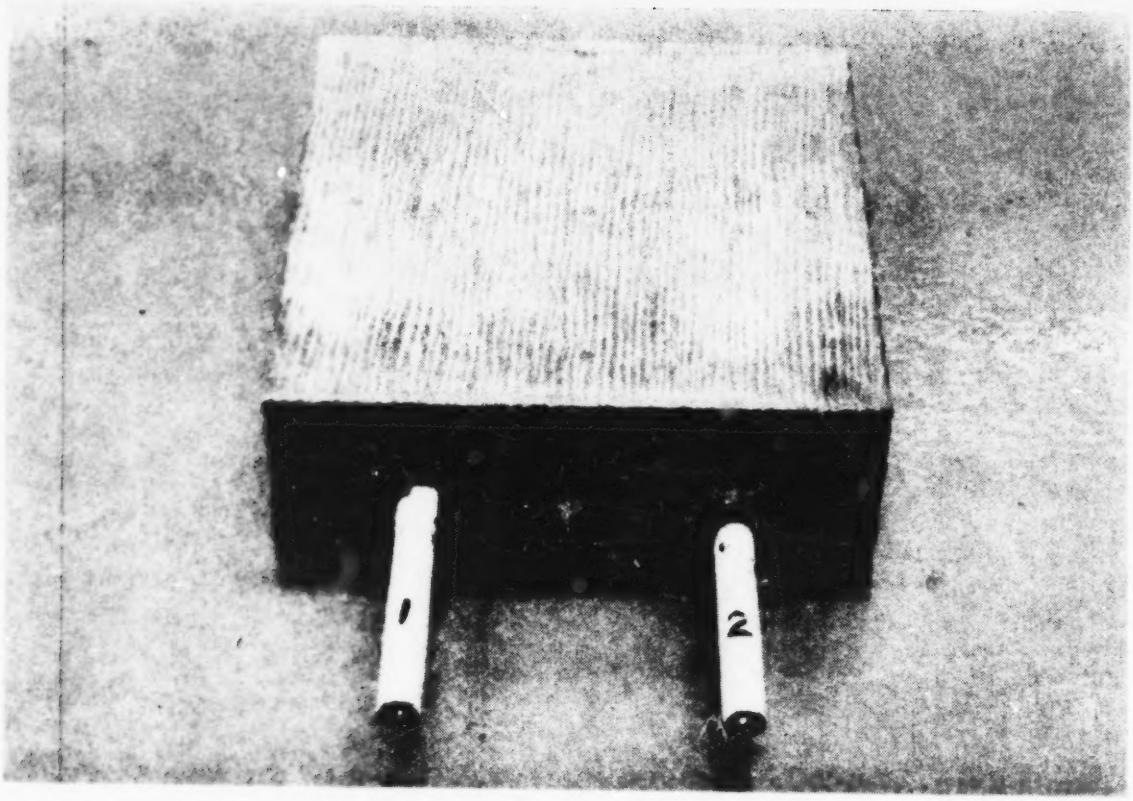

Figure 1. A typical test slab

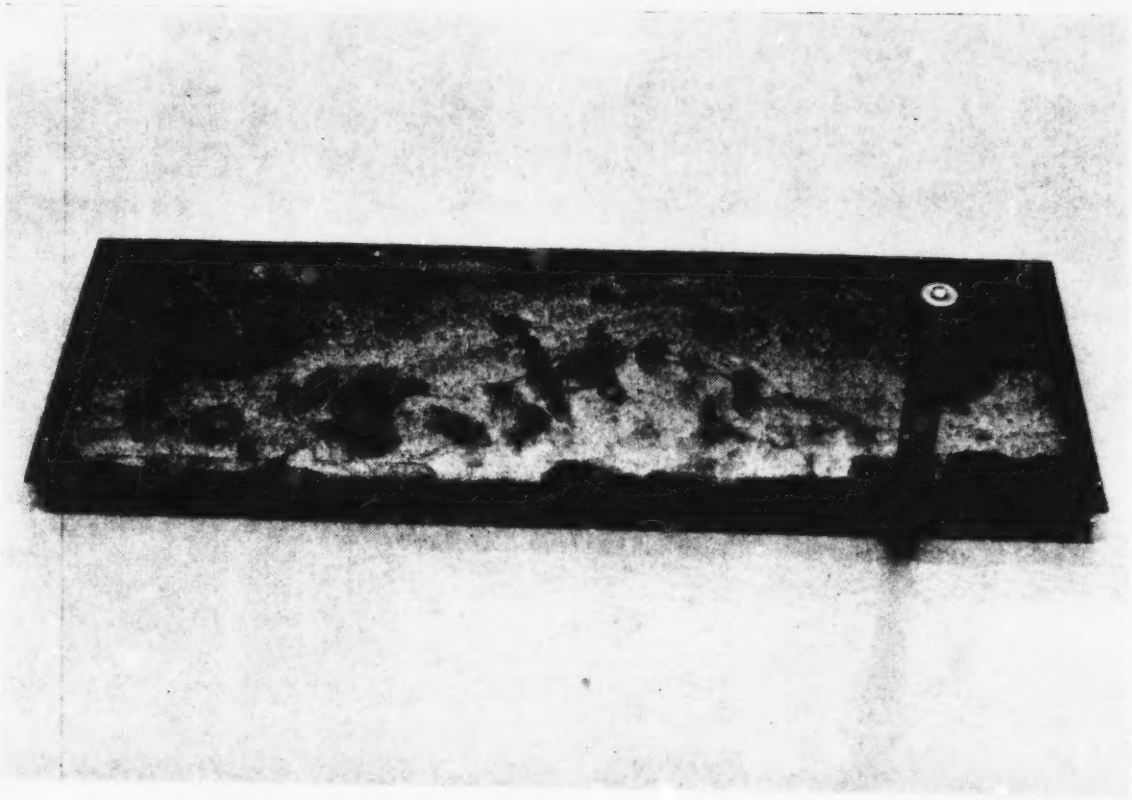

Figure 2. External cathode for corrosion measurement

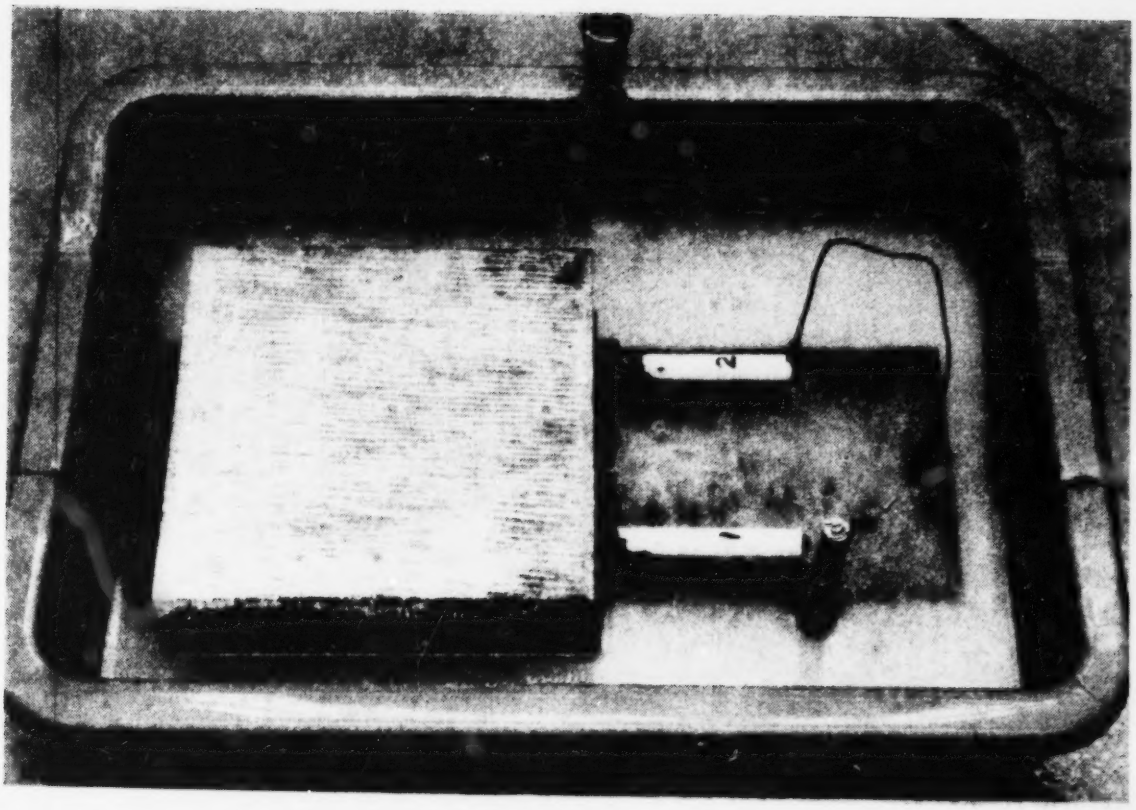

Figure 3. Test arrangement for corrosion measurement

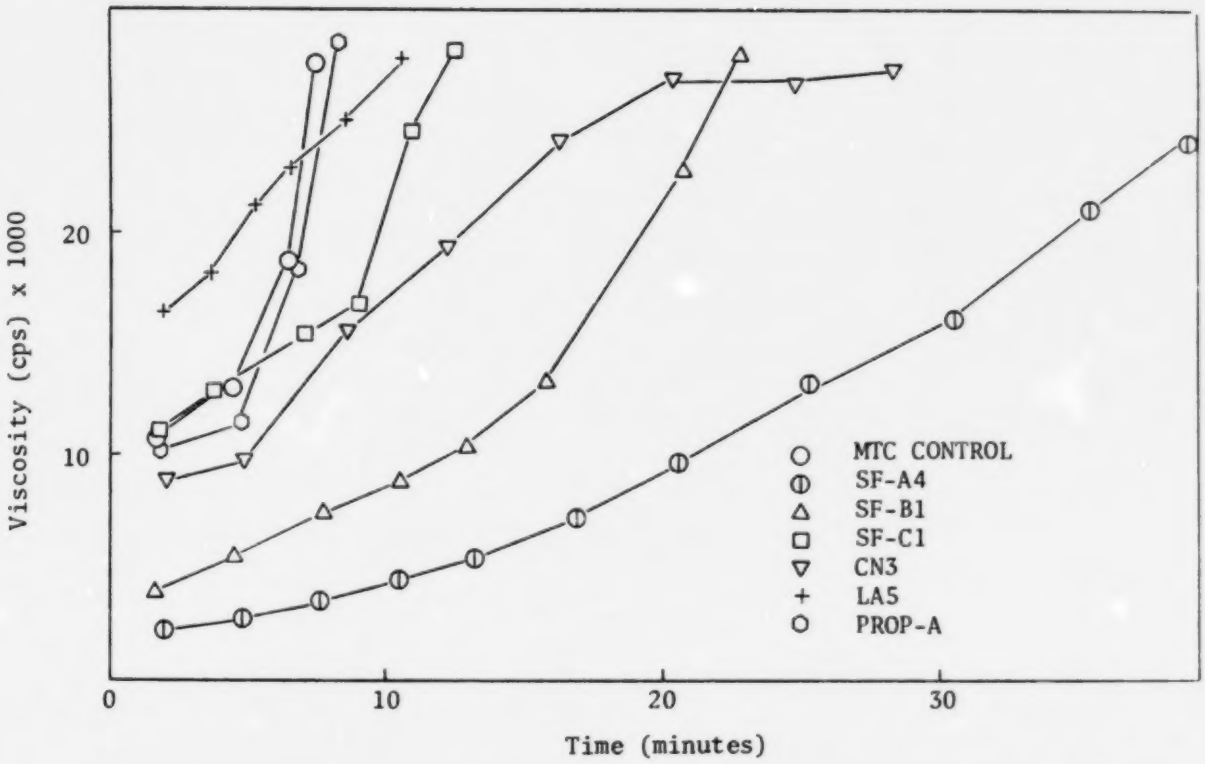

Figure 4. Viscosity of test grouts: MTC control, 5 % silica fume (SF-A4), 10 % silica fume (SF-B1), 15 % silica fume (SF-C1), calcium nitrite (CN3), latex (LA5), and proprietary mix (PROP-A)

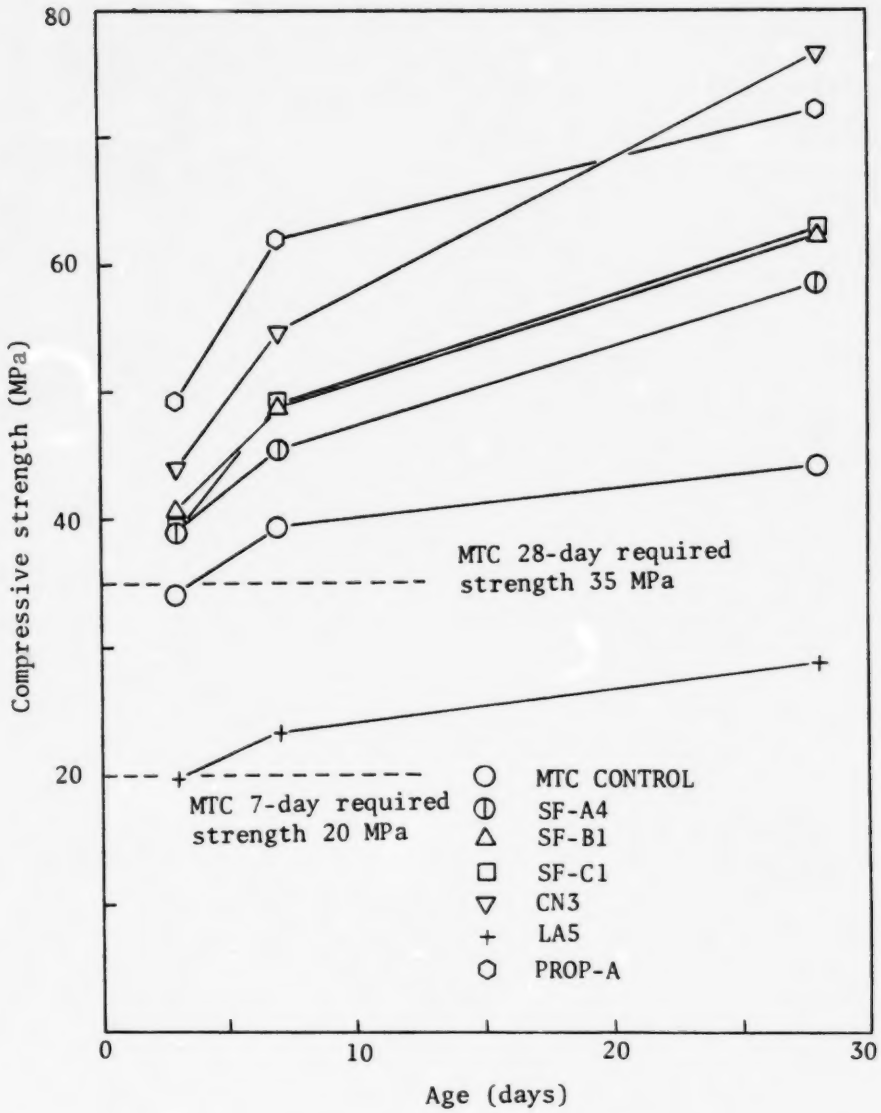

Figure 5. Compressive strength for test grouts: MTC control, 5 % silica fume (SF-A4), 10 % silica fume (SF-B1), 15 % silica fume (SF-C1), calcium nitrite (CN3), latex (LA5), and proprietary mix (PROP-A)

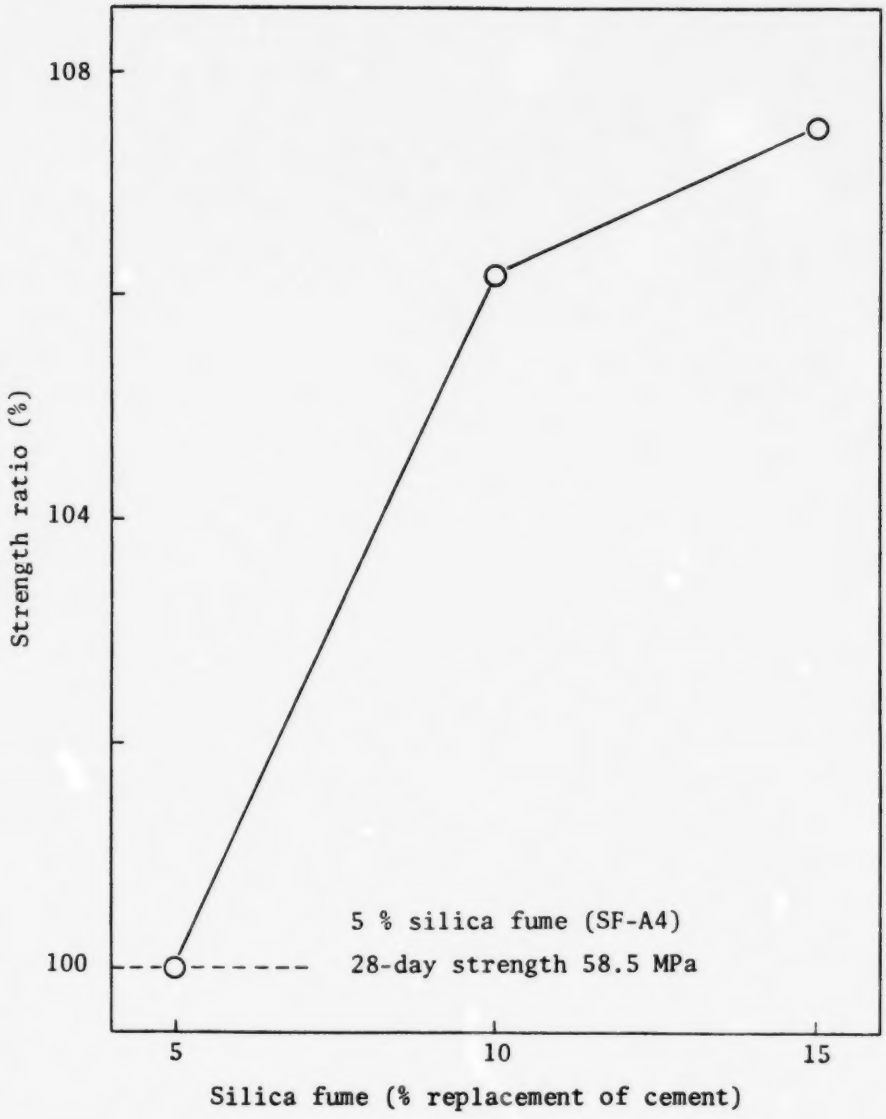

Figure 6. Effect of silica fume on 28-day compressive strength

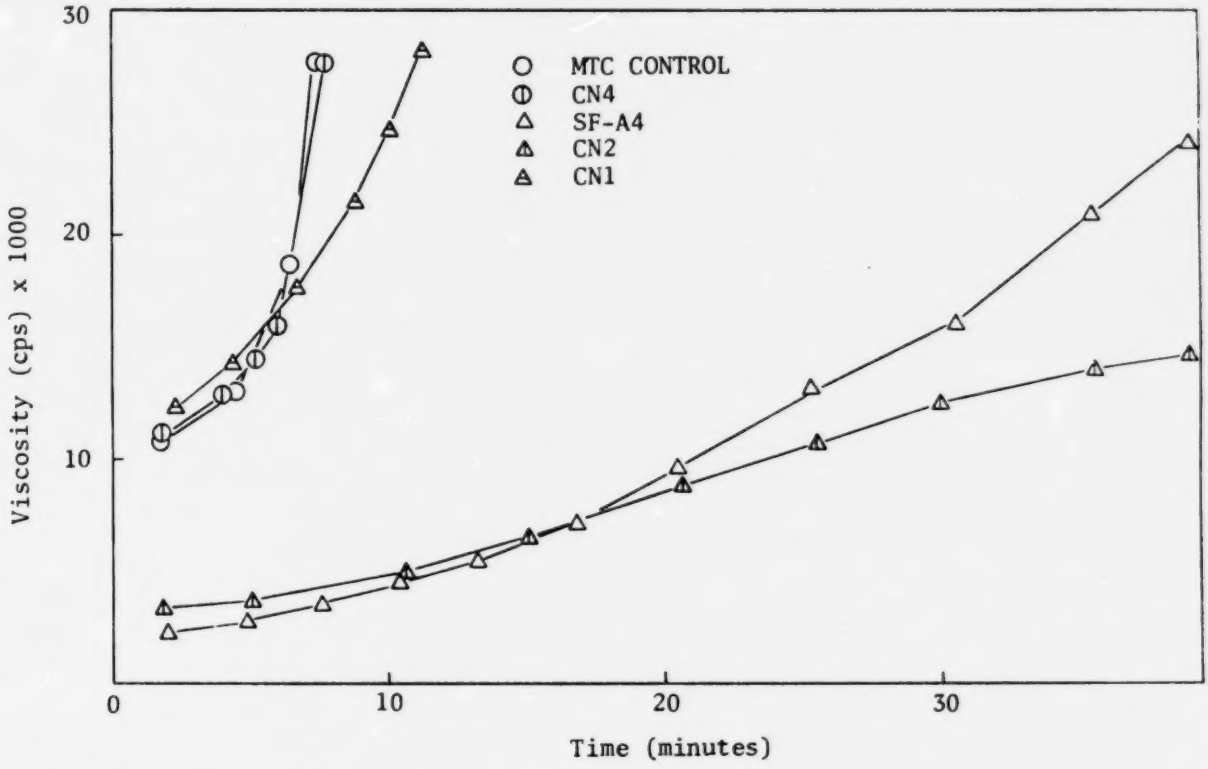

Figure 1. Effect of calcium nitrite on viscosity: MTC control (0 % calcium nitrite powder), CN4 (control + 0.5 % calcium nitrite powder), SF-A4 (0 % calcium nitrite powder), CN2 (SF-A4 + 0.5 % calcium nitrite powder), and CN1 (SF-A4 + 1 % calcium nitrite powder)

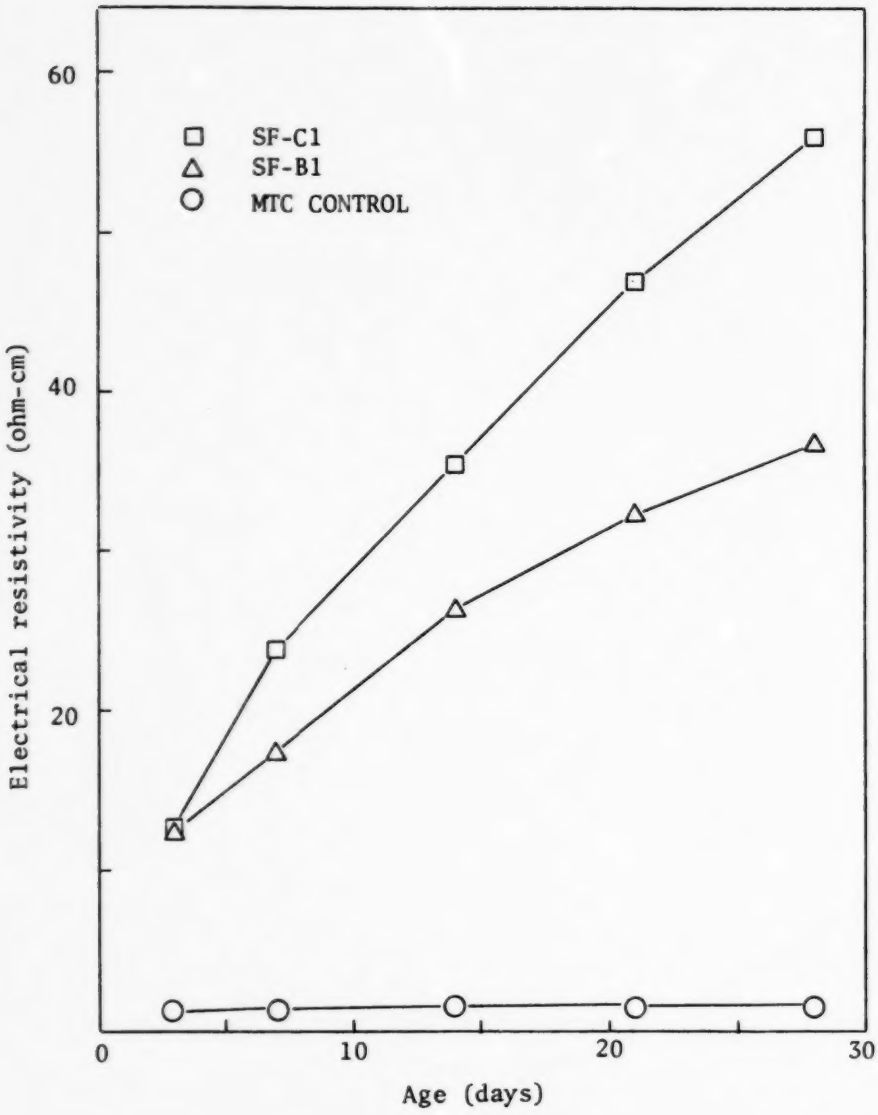

Figure 8. Electrical resistivities for test grouts: MTC control, 10 % silica fume (SF-B1), and 15 % silica fume (SF-C1)

Appendix A. MTC mixes

Mix:	MTC1	MTC2	MTC3	MTC4	MTC5	MTC6
Mix Proportion:						
Water/cement ratio	0.45	0.50	0.47	0.47	0.50	0.48
Type 30 cement (Kg)	10	10	10	10	10	10
Distilled water (Kg)	4.5	5.0	4.7	4.7	5.0	4.8
Porzite L73 (g)	38	38	38	40	40	47*
Aluminum powder (g)	0.5	0.5	0.5	0.67	0.67	0.67
Test:						
Flow time (sec)	19.6	12.3	13.2	13.5	12.9	13.2
Expansion (%)	6.0	5.3	5.6	7.6	7.2	7.5
Bleeding	negligible	negligible	negligible	negligible	negligible	negligible
Strength 3-day (MPa)	-	-	-	35.3	30.8	34.1
7-day (MPa)	-	-	-	40.6	35.5	39.4
28-day (MPa)	-	-	-	45.0	39.6	44.3
Absorption (%)+	-	-	-	-	-	29.5
Bulk density+	-	-	-	-	-	1.83
pH	-	-	-	12.5-13.5	12.5-13.5	12.5-13.5

* 47g is equivalent to 40 ml
+ After immersion

Notes:
1. An uncoated aluminum powder was used in all the mixes.
2. All the mixes thickened quickly.
3. Mix MTC6 was chosen as the control.

Appendix B. Silica fume (SF) mixes: 5 % Silica fume (SF-A)

Mix:	SF-A1	SF-A2	SF-A3	SF-A4	SF-A5
Mix Proportion:					
Water/solid ratio*	0.30	0.50	0.32	0.33	0.35
Type 10 cement (Kg)	9.5	9.5	9.5	9.5	9.5
Silica fume (Kg)	0.5	0.5	0.5	0.5	0.5
Distilled water (Kg)	3.0	5.0	3.2	3.3	3.5
Melment F10 (g)	100	100	100	100	100
Aluminum powder (g)	–	–	0.67	0.67	0.67
Test:					
Flow time (sec)	16.4	10.4	14.8	13.7	12.3
Expansion (%)	–	–	8.8	8.5	7.5
Bleeding	negilgible	1 %	negilgible	negilgible	negilgible
Strength 3-day (MPa)	51.7	–	39.6	38.8	37.6
7-day (MPa)	62.0	–	47.5	46.5	45.1
28-day (MPa)	–	–	59.6	58.5	57.2
Absorption (%)+	–	–	19.3	20.4	22.0
Bulk density+	–	–	1.97	1.96	1.96
pH	–	–	12.5-13.5	12.5-13.5	12.5-13.5

* Solids = cement + silica fume
+ After immersion

Notes:
1. An uncoated aluminum powder was used in all the mixes.
2. All the mixes were thixotropic.
3. Plastic shrinkage was observed in mixes SF-A1 and SF-A2.

Appendix B. Silica fume (SF) mixes: 10 % silica fume (SF-B) and 15 % silica fume (SF-C)

Mix:	SF-B1	SF-B2	SF-B3	SF-C1	SF-C2	SF-C3
Mix Proportion:						
Water/solid ratio*	0.33	0.36	0.38	0.33	0.36	0.38
Type 10 cement (Kg)	9.0	9.0	9.0	8.5	8.5	8.5
Silica fume (Kg)	1.0	1.0	1.0	1.5	1.5	1.5
Distilled water (Kg)	3.3	3.6	3.8	3.3	3.6	3.8
Melment F10 (g)	100	100	100	100	100	100
Aluminum powder (g)	0.67	0.67	0.67	0.67	0.67	0.67
TEST:						
Flow time (sec)	13.9	12.6	11.8	14.5	12.4	12.0
Expansion (%)	7.0	7.6	7.0	6.8	7.3	6.4
Bleeding	none	none	negilgible	none	none	negiligble
Strength 3-day (MPa)	40.8	36.8	33.8	38.9	35.2	31.4
7-day (MPa)	48.9	45.8	40.9	49.3	46.3	43.0
28-day (MPa)	62.1	58.8	54.9	62.9	56.0	52.6
Absorption (%)+	20.5	24.0	24.4	20.4	24.8	26.1
Bulk density+	1.96	1.92	1.90	1.96	1.92	1.90
pH	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5

* Solids = cement + silica fume
+ After immersion

Notes:
1. An uncoated aluminum powder was used in all the mixes.
2. All the mixes were thixotropic.

Appendix C. Calcium nitrite (CN) mixes

Mix:	CN1	CN2	CN3	CN4
Mix Proportion:				
Water/solid ratio*	0.33	0.33	0.33	0.48
Cement (Kg)**	9.5	9.5	9.0	10
Silica fume (Kg)	0.5	0.5	1.0	-
Distilled water (Kg)	3.3	3.3	3.3	4.8
Melment F10 (g)	100	100	100	-
Porzite L73 (g)	-	-	-	47
Aluminum powder (g)	0.67	0.67	0.67	0.67
Calcium nitrite powder (g)	100	50	50	50
Test:				
Flow time (sec)	14.9	13.4	13.7	12.6
Expansion (%)	1.0	1.5	1.7	2.1
Bleeding	none	negilgible	none	1.5 %
Strength 3-day (MPa)	44.6	48.6	44.0	34.0
7-day (MPa)	59.3	52.7	54.8	39.5
28-day (MPa)	73.5	72.1	76.5	49.8
Absorption (%)+	21.6	21.7	21.5	30.4
Bulk density+	2.05	2.05	2.05	1.91
pH	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5

* Mixes CN1, CN2, and CN3: solids = Type 10 cement + silica fume
  Mix CN4: solids = Type 30 cement
**Type 10 cement was used in CN1, CN2, and CN3; Type 30 cement was used in CN4.
+ After immersion

Notes:
1. An uncoated aluminum powder was used in all the mixes.
2. Mix CN1 thickened very quickly.

Appendix D. Latex (LA) mixes

Mix:	LA1	LA2	LA3	LA4	LA5	LA6
Mix Proportion:						
Water/cement ratio	0.35	0.30	0.50	0.35	0.30	0.33
Type 10 cement (Kg)	10	10	10	10	10	10
Latex (g)	3125	3125	3125	3125	3125	3125
Distilled water (g)	1875	1375	3375	1875	1375	1675
Melment F10 (g)	100	100	-	-	-	-
Aluminum powder (g)	0.67	0.67	0.67	0.67	0.67	0.67
Test:						
Flow time (sec)	11.8	13.9	10.4	13.2	16.5	14.1
Expansion (%)	7.5	7.8	7.5	8.0	8.7	8.7
Bleeding	severe	negilgible	severe	little	negligible	negilgible
Strength 3-day (MPa)	16.5	21.3	7.6	15.1	19.7	17.3
7-day (MPa)	19.0	24.5	10.4	18.7	23.4	20.2
28-day (MPa)	27.0	29.9	14.3	23.3	28.7	26.7
Absorption (%)+	21.9	18.1	32.8	21.3	16.7	19.2
Bulk density+	1.77	1.78	1.66	1.75	1.79	1.77
pH	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5

+ After immersion

Note:
An uncoated aluminum powder was used in all the mixes.

Appendix E. Flyash (FA) mixes

Mix:	FA1	FA2	FA3
Mix Proportion:			
Water/solid ratio*	0.33	0.33	0.45
Type 10 cement (Kg)	7.0	7.0	7.0
Flyash (Kg)	3.0	3.0	3.0
Distilled water (Kg)	3.3	3.3	4.5
Melment F10 (g)	300	400	100
Aluminum powder (g)	0.67	0.67	0.67
Test:			
Flow time (sec)	40.9	40.1	12.0
Expansion (%)	7.8	8.1	7.3
Bleeding	severe	severe	severe
Strength 3-day (MPa)	27.9	27.3	19.3
7-day (MPa)	34.6	33.4	23.0
28-day (MPa)	48.2	52.4	35.8
Absorption (%)+	22.0	24.2	30.3
Bulk density+	2.01	2.03	1.89
pH	12.5-13.5	12.5-13.5	12.5-13.5

* Solids = Type 10 cement + flyash
+ After immersion

Notes:
1. An uncoated aluminum powder was used in all the mixes.
2. All the mixes exhibited severe bleeding and segregation.
3. All the mixes were not fully set after 24 hours.

Appendix F. Proprietary grouting admixtures (PROP): PROP-A

Mix:	PROP-A1	PROP-A2	PROP-A3
Mix Proportion:			
Water/solid ratio*	0.33	0.35	0.39
PROP-A (Kg)	10	10	10
Distilled water (Kg)	3.3	3.5	3.9
Test:			
Flow time (sec)	23.0	16.8	13.1
Expansion (%)	-	-	-
Bleeding	negligible	**	**
Strength 3-day (MPa)	49.3	42.2	32.4
7-day (MPa)	61.9	58.3	46.7
28-day (MPa)	72.0	68.4	62.7
Absorption (%)+	21.9	22.3	25.5
Bulk density+	2.08	2.05	1.98
pH	12.5-13.5	12.5-13.5	12.5-13.5

* Solids = PROP-A
**Bleeding and segregation
+ After immersion

Notes:
1. All the mixes thickened very quickly. It was difficult to remove the grouts from the graduated cylinders one hour after mixing.
2. Small plastic shrinkage was observed in all the mixes.

Appendix F. Proprietary grouting admixtures (PROP): PROP-B

Mix:	PROP-B1	PROP-B2	PROP-B3	PROP-B4
Mix Proportion:				
Water/solid ratio*	0.48	0.38	0.38	0.40
Type 30 cement (Kg)	10	-	-	-
Type 10 cement (Kg)	-	10	9.0	9.0
Silica fume (Kg)	-	-	1.0	1.0
Distilled water (Kg)	4.8	3.8	3.8	4.0
PROP-B (g)	100	100	100	100
Test:				
Flow time (sec)	12.6	13.4	15.6	13.0
Expansion (%)	11	15	13	14
Bleeding	1 %	1.5 %	none	none
Strength 3-day (MPa)	19.9	27.5	24.0	21.7
7-day (MPa)	21.6	30.2	29.0	28.1
28-day (MPa)	25.3	36.2	34.1	32.1
Absorption (%)+	27.9	24.0	24.5	26.1
Bulk density+	1.79	1.79	1.83	1.76
pH	12.5-13.5	12.5-13.5	12.5-13.5	12.5-13.5

* Mix PROP-B1: solids = Type 30 cement
Mix PROP-B2: solids = Type 10 cement
Mixes PROP-B3 and PROP-B4: solids = Type 10 cement + silica fume
\+ After immersion

Appendix F. Proprietary grouting admixtures (PROP): PROP-C and PROP-D

Mix:	PROP-C1	PROP-C2	PROP-D1	PROP-D2	PROP-D3
Mix Proportion:					
Water/solid ratio*	0.40	0.45	0.45	0.60	0.68
Type 10 cement (Kg)	10	10	8.3	8.3	8.3
Distilled water (Kg)	4.0	4.5	4.5	6.0	6.8
PROP-C (g)	100	100	-	-	-
PROP-D (Kg)	-	-	1.7	1.7	1.7
Test:					
Flow time (sec)	14.4	12.4	**	**	15.2
Expansion (%)	21	20			-
Bleeding	negligible	severe			negligible
Strength 3-day (MPa)	-	-			12.4
7-day (MPa)	22.2	17.0			20.7
28-day (MPa)	28.5	22.5			33.1
Absorption (%)+	25.2	29.7			53.9
Bulk density+	1.97	1.76			1.67
pH	12.5-13.5	12.5-13.5			12.5-13.5

* Mixes PROP-C1 and PROP-C2: solids = Type 10 cement
  Mixes PROP-D1 to PROP-D3: solids = Type 10 cement + PROP-D
**Too thick to be measured
+ After immersion

Notes:
1. All the PROP-D mixes thickened very quickly.
2. Plastic shrinkage was observed in mix PROP-D3. Large shrinkage cracks were seen on the 50 mm cubes of this mix.